Producing ethanol from corn using nuclear-generated steam

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The use of low-temperature steam from nuclear power plants for ethanol production could help improve the fuel's economics.

THE PRODUCTION OF fuel ethanol from corn increased from about 1.6 billion gallons per year in 2000 to 5 billion gal/year in 2006, and further large expansions in production are predicted. More than half of the nonsolar energy required for ethanol production, from growing the corn to converting it to fuel-grade alcohol, is for low-temperature heat to distill the alcohol and dry the animal feed by-products. For a large ethanol plant producing 100 million gallons of fuel ethanol per year, about 80 MWt of steam is required, which represents a potential market for 150-psi (about 180 °C) steam from existing light-water nuclear power plants. This low-temperature steam is of lower value for electricity production, but it could significantly improve ethanol economics, create an expanded market for nuclear energy, reduce greenhouse gas emissions, and reduce foreign oil imports.

President Bush in his 2007 State of the Union address stated, "We must increase the supply of alternative fuels by setting a mandatory fuels standard to require 35 billion gallons of renewable and alternative fuels by 2017." If ethanol is used to meet that goal, almost 30 gigawatts of low-temperature steam will be required.

The idea of using nuclear power plants to coproduce electricity and heat is not new. Canadian nuclear power plants have been used to produce electricity and steam, with the steam used for the isotopic separation of heavy water and other industrial purposes. For about a decade, steam produced by the Bruce nuclear power station in Ontario was used for ethanol production. Plants in Switzerland and Russia produce both electricity and district heat.

Applications, however, have been limited. One reason is that fossil fuel prices have been low. Equally important, very few markets exist for large quantities of steam. It is not usually worth the effort to modify a nuclear power plant producing 1500–4500 MW of steam in order to produce a few megawatts of heat to meet a local industry or district heating need.

The development of fuel ethanol production from corn is creating a potential new market for large quantities of steam from light-water reactors. The size of corn-to-ethanol plants is rapidly increasing, as is the corresponding steam demand per plant. The plants that produce ethanol from corn operate continuously, resulting in steady-state demand for steam. In the production of ethanol, the primary cost is corn, followed by the cost of energy. Thus, there is an economic incentive to consider using steam from nuclear power plants. Finally, the steam demand is located in rural areas where nuclear power plants already exist.

There is one economic limitation, however. The cost of the corn delivered to a fuel ethanol plant is strongly dependent upon the cost of transporting the corn from the farm. The only nuclear reactors that can economically provide steam for this application are in the Corn Belt, along the Mississippi River or other waterways where cheap barge transportation is available, or where there is a demand for the by-products of ethanol production.

The accompanying figure shows corn-to-ethanol plants that are under construction, existing nuclear power plants, and the Corn Belt. It provides a perspective as to which nuclear plants are potential candidates for supplying steam to future ethanol plants.

Ethanol demand and production

Ethanol is added to gasoline for three reasons. First, ethanol, which has an octane rating of 113 to 115, is used as an octane enhancer. It is replacing MTBE, a hydroscopic octane enhancer that has caused significant groundwater contamination and has major legal liabilities associated with its use. Second, ethanol is used to meet the minimum oxygen-content requirements for gasoline. Some oxygen is required in gasoline to minimize carbon-monoxide pollution and pollutants that produce ozone. Last, ethanol is a fuel, both when mixed with gasoline and when used by itself. However, the value of ethanol as an octane enhancer and an oxidant is significantly higher than its fuel value.

The cost of fuel ethanol has been decreasing for a number of reasons. The production cost of corn has gone down because of improved production methods that have reduced the fuel, pesticide, and fertilizer inputs per bushel of corn. The efficiency of corn-to-ethanol plants has also significantly increased. Finally, the government has offered multiple incentives for ethanol production.

The production of fuel ethanol has two major steps: growing the corn, and converting it to ethanol. More than half the energy inputs are used in the process of converting corn to ethanol. Corn contains carbohydrates and proteins. In the corn-to-ethanol process, the fermentation step converts the carbohydrates to ethanol, using about two-thirds of the corn kernel. The nonfermentable components, which consist primarily of proteins, and the other by-products of fermentation become animal feed or are converted to other useful products. Within the ethanol plant, the primary energy input is heat to distill the ethanol from water. Heat is also required to dry the by-products so they can be stored and shipped without rotting, and to sterilize the mash before adding yeast to start the fermentation process.

There are lingering debates associated with fuel ethanol production. For instance, the energy value of the fossil fuel inputs to grow the corn and convert it to ethanol is

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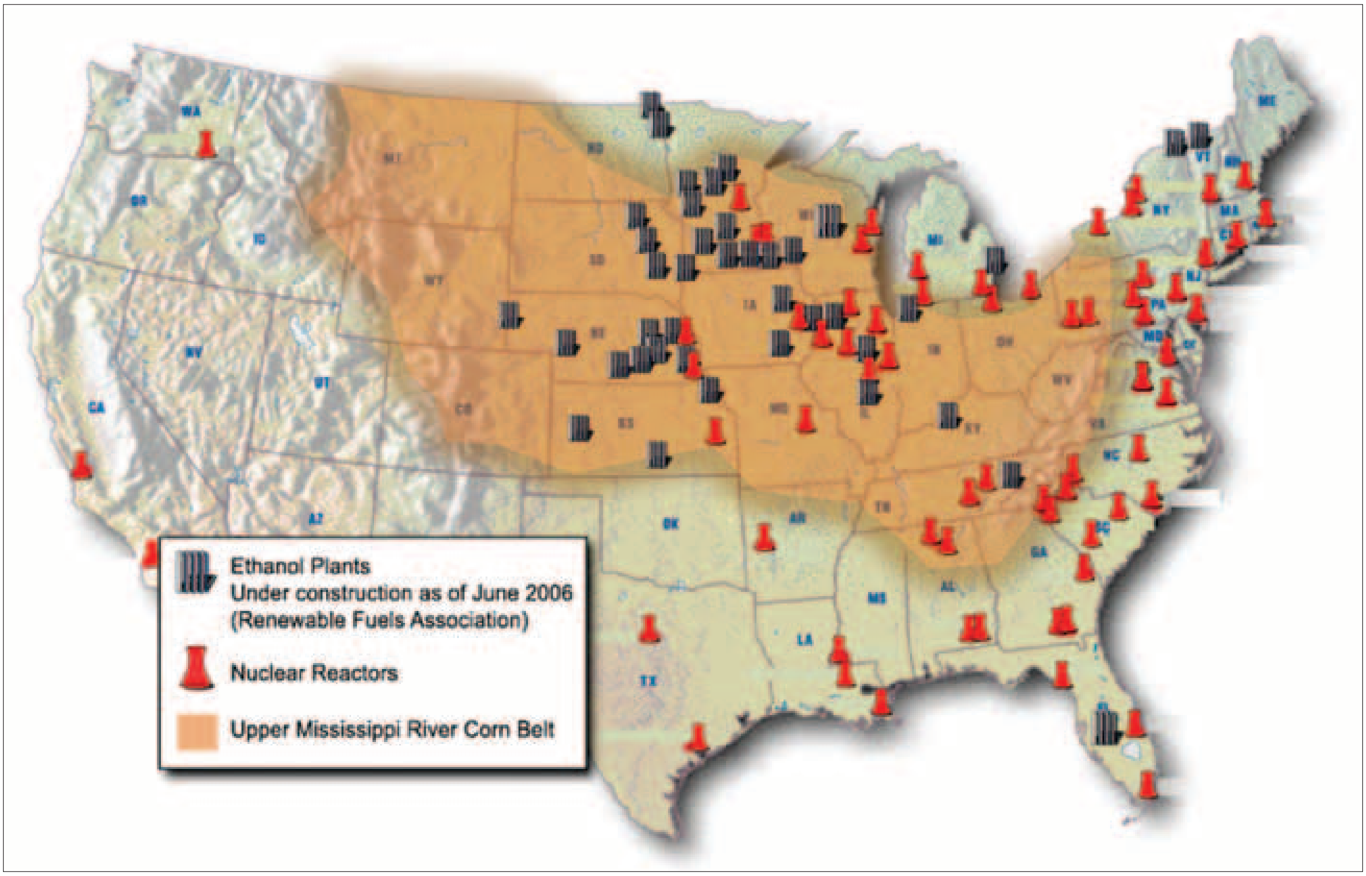

Ethanol plants under construction, existing nuclear power plants, and the Corn Belt (Source: DOE)

70 percent to 80 percent of the energy value of the ethanol itself. Liquid fuels, however, are more valuable than natural gas or coal inputs in the corn-to-ethanol production process, and so the final product represents a net gain. The greenhouse gas releases from consuming fossil fuels—from growing the corn through the production of ethanol—are only about 20 percent less than from the alternative of producing gasoline from crude oil with an equivalent energy value.

If nuclear energy is used to support ethanol production, however, fossil fuel inputs can be dramatically reduced. The conversion of corn to ethanol primarily requires low-quality, low-cost steam—something nuclear power plants are very good at producing. Using low-quality steam from nuclear power plants in the corn-to-ethanol production process would reduce fossil fuel inputs and the resultant greenhouse gas emissions for the entire process of growing the corn and converting it to ethanol by almost half.

The production of fuel ethanol from corn is limited by the availability of and competing uses for corn, but much larger quantities of biomass exist in the form of grasses and trees. The potential fuel production from these biomass sources is an order of magnitude greater than from corn. Most of this biomass is cellulose that cannot be directly converted to ethanol. The technology to convert these forms of biomass into fuels is currently being taken from laboratory- to industrial-scale applications through major programs in the United States and elsewhere.

Like ethanol from corn, not all of the biomass can be converted to ethanol. Unfortunately, the nonfermentable components are not usable as animal feed. It is currently proposed that this residual biomass be burned to provide the heat for ethanol distillation. If steam were available from nuclear power plants, this residual biomass could be converted into additional liquid fuels using other biomass-to-liquid-fuel processes. The cellulose-to-ethanol biomass options offer a longer-term and potentially much larger market for steam from nuclear power plants to meet our liquid-fuel transportation needs.

Coproducing electricity and steam

Since the beginning of the development of nuclear energy, numerous studies, including the International Atomic Energy Agency's 2002 study, "Market Potential for Non-electric Applications of Nuclear Energy," have been conducted, and multiple reactors have been built to produce electricity and steam. The steam has been used for district heating (45 reactors), desalination (10 reactors), and industrial uses (25 reactors). Coproduced steam, however, has never been a major product of nuclear reactors for two reasons: (1) There are few customers near rural nuclear plant sites, and (2) most of the markets for steam are so small as to not be worth the complications of coproducing steam and electricity. The production of fuel ethanol from corn today, and the future production of fuel ethanol from other forms of biomass, change this. The need is for large quantities of steam in rural areas—the same areas in which nuclear power plants are located.

For ethanol production, the steam provided by the reactor would be condensed at the ethanol plant, and warm water would be returned to the nuclear power plant. Almost all of the heat would come from condensing the steam. Modern steam systems would allow more than a mile of separation between the reactor and the ethanol plant. Ethanol plants would have to be located beyond any security perimeter, because such plants require easy access by grain trucks, trains, or barges. The separation required to avoid security concerns would be more than that necessary to ensure safety against fires and other accidents in the ethanol plant.

No fundamental technical, regulatory, or economic barriers stand in the way of the cogeneration of electricity and steam for ethanol production, and sufficient experience exists from current and decommissioned reactors that have produced steam and electricity. If a utility provides steam, appropriate commercial clauses must address what to do when steam is not available. Such considerations might result in a preference for sites with multiple reactors or with both nuclear and fossil units, where there would be a higher assurance of constant steam production.

There are also the associated issues of standards and other components of the technical infrastructure that support commercial enterprises. The potential economic, national security (i.e., a reduced dependence on imported oil), and environmental benefits, however, strongly support the commercialization of this use of nuclear energy at existing nuclear sites in areas where large quantities of low-cost corn are available.

The economics of low-pressure steam from nuclear plants is favorable relative to steam produced by natural gas, oil, or coal. Light-water reactor efficiencies are about 33 percent. That is, one unit of electricity is lost for every three units of heat diverted to other applications. Because ethanol production requires low-temperature steam, the high-temperature, high-pressure steam from the reactor would first be sent through the high-pressure turbines for the production of electricity before the energy in that steam is used for ethanol production. Based on the price of electricity, the cost of low-temperature steam from a nuclear power plant is about half the cost of steam from natural gas. Last, ethanol plants traditionally operate at constant production but have the potential to shift some of the steam demand to nighttime. The largest use of energy in the ethanol production process is for distillation, which must operate at steady state. However, the energy demand for drying the animal feed by-products could potentially be shifted to nighttime.

There are business risks that must be addressed, and the appropriate business models must be developed. For a commercial enterprise, timing is important, and thus a critical issue is the time required to obtain license amendments and permits for the sale of steam from existing nuclear power plants. Investment strategies and shareholder support will ultimately be a function of the "risk-reward" equation. There is also the important role of government to help overcome institutional and other barriers for the first-of-a-kind plant that would join two industries with very different business models and concerns.

A goal of the U.S. government is to displace 30 percent of the nation's gasoline use by 2030, initially by using corn, and then cellulose, for the production of ethanol. That is an extraordinary challenge that requires increasing ethanol production by more than an order of magnitude. For this scale of operation, the total steam demand at a few hundred plants would be tens of gigawatts. Because of the potential for highly favorable economics and for making a major contribution to reducing our national dependence on foreign oil, this is a nuclear future that the nation should explore today. NN